Recycler Status and Plans

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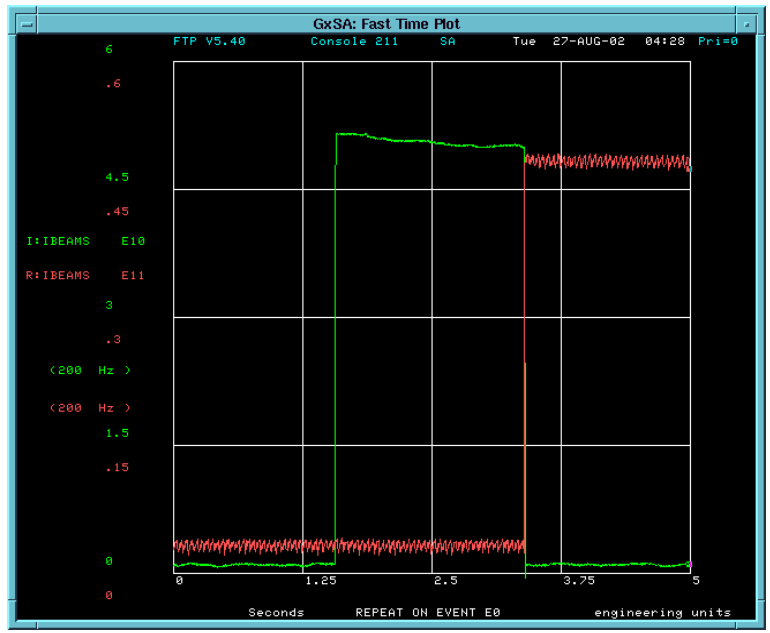
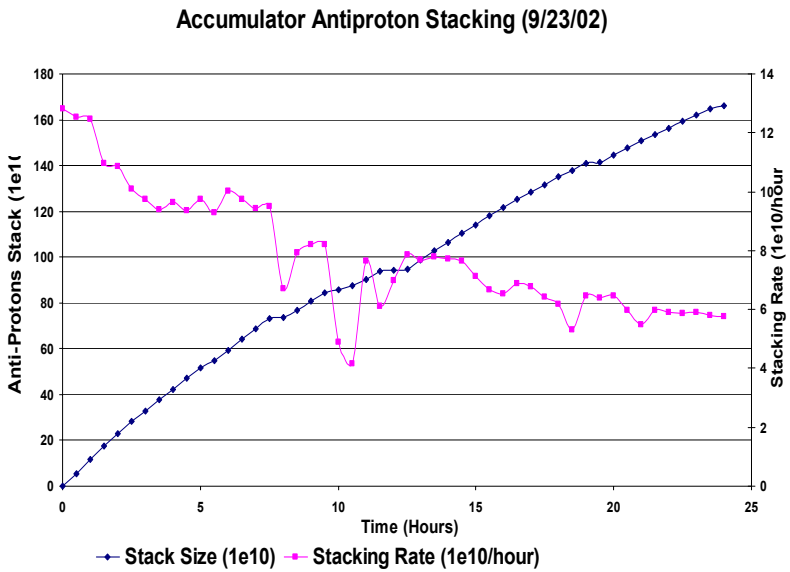


- Introduction to the Recycler Ring
- Recycler Improvements
- Present status and upgrade plans
- Summary

Introduction to the Recycler Ring

- The Recycler Ring is designed to store and cool antiprotons at 8.9 GeV/c. In the final configuration it will also Recycle antiproton from the Tevatron at the end of store.

- The Accumulator stacking rate decreases as the stack size in the Accumulator increases .



- An initial stacking rate of 12.4e10/hr has been achieved in the accumulator. (Sept. 24th 2002)

- Transfer antiproton from Accumulator to Recycler will be done at small stack sizes, 30-40e10 to keep the stacking rate in the Accumulator high.

Recycler Study and Upgrade Goals

	Goals
Number of stored antiprotons	*2e12 (5e12 Run IIb)*
Transfer efficiency(Acc→RR)	*>95%*
Stacking efficiency	*>90%*
Lifetime (2e12) (hrs)	*100(200-300)*
Equilibrium Normalized Emittance	*<10 pi mm-mr*
Emittance Growth rate	*~2 pi mm-mr/hr*
Antiproton Recycling Efficiency	>50%*
Longitudinal Emittance	<54 eV-Sec

* This will depend on the emittance of beam at the end of store.

Recycler Upgrades (Since initial installation)

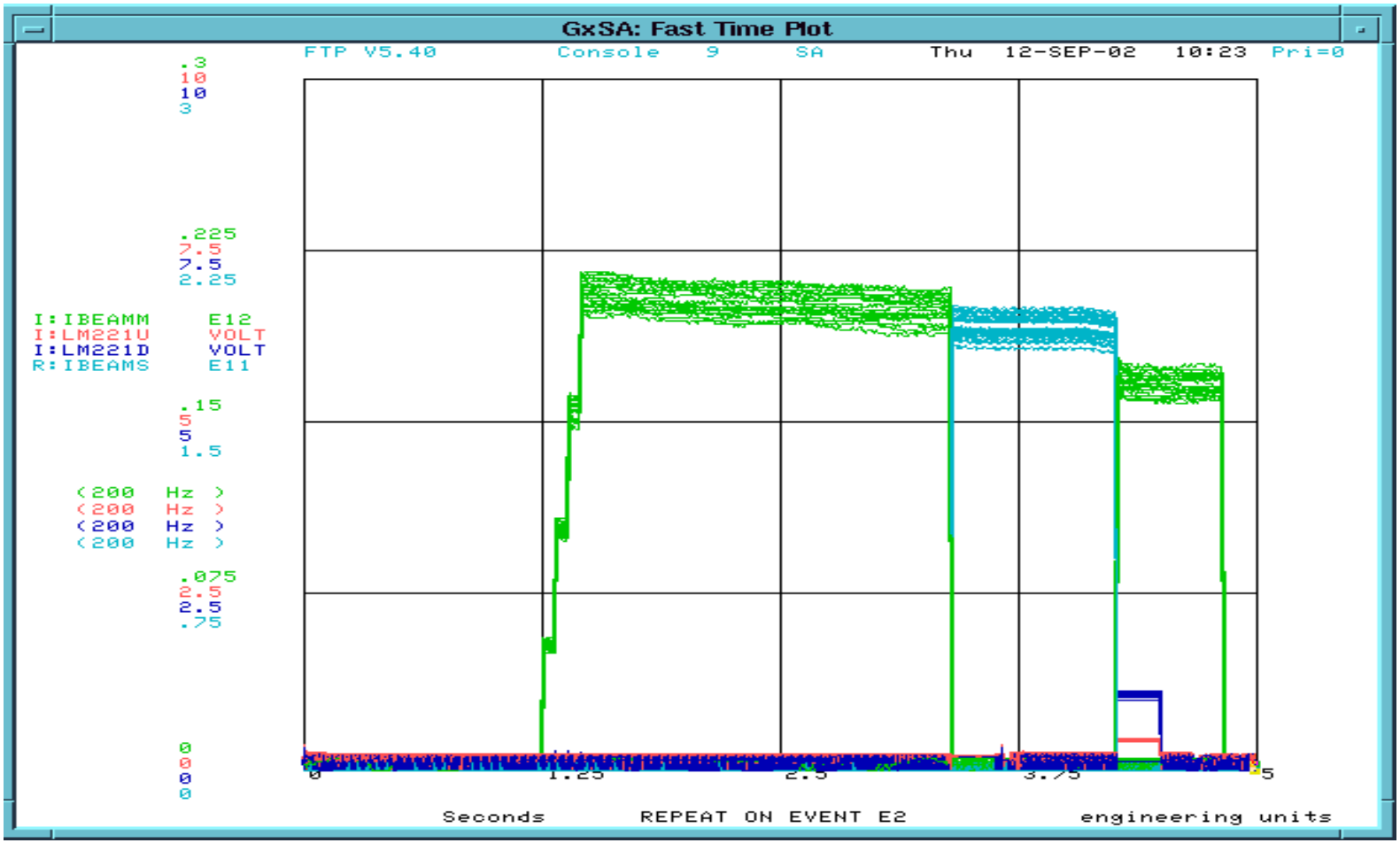
- Recycler End shim replacement
- Removal of magnetic heater tapes
- Alignment of beam pipes and BPMs
- Removal of high beta insert
- Realignment of All Recycler magnets with new fudicial.
- Install electromagnetic dipole correctors at each half cells, additional quadrupole and sextupoles.
- Install new magnetic shielding.
- Install new heater tapes inside each CFM and on beam pipes.
- Install new calibration circuit for all BPMs and calibrate every preamps.
- Install two scrapers and a new longitudinal Schottky detectors
- Install remote movable Stochastic cooling tanks
- Perform R&D on two vacuum sector by doubling Ion Pump.

Recycler Studies

During last several months the Recycler studies have concentrated on the following topics

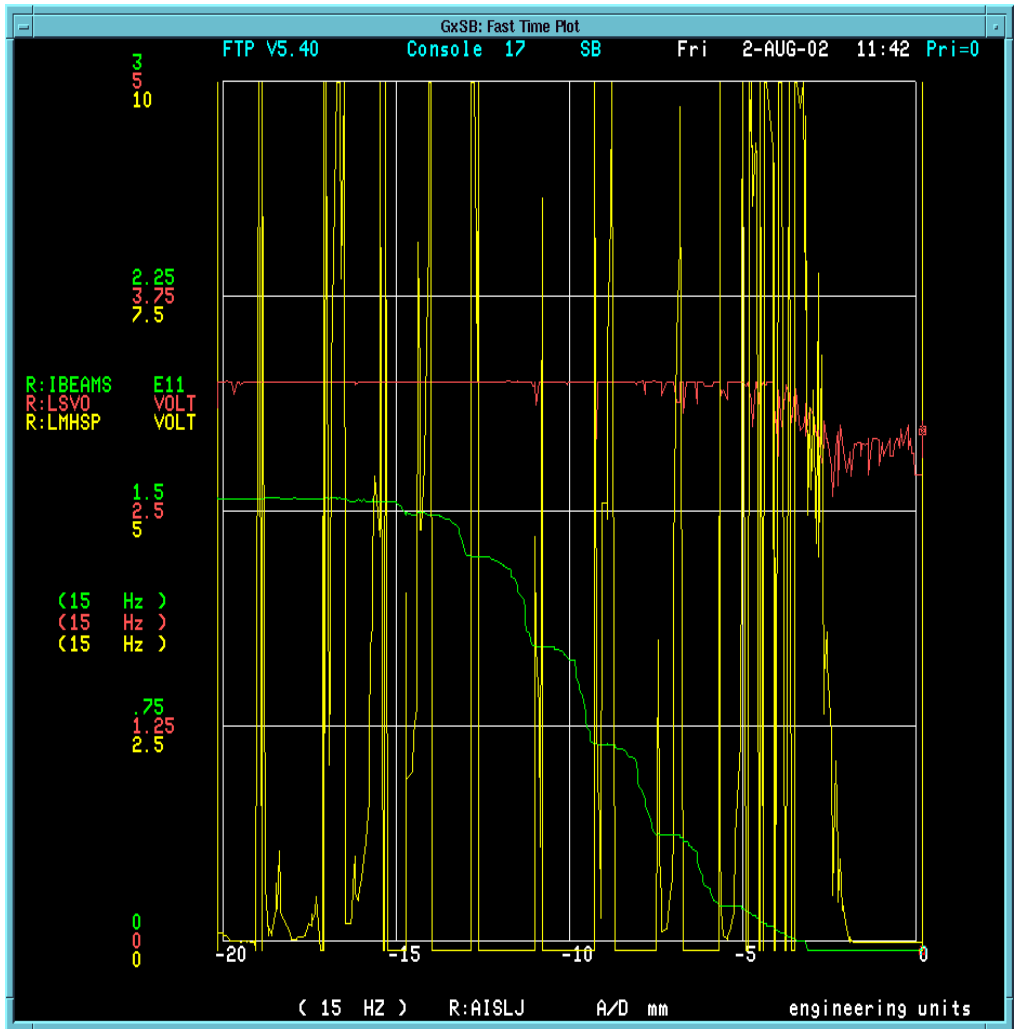
- Injection
  - Efficiency of protons and antiprotons
  - Emittance growth at injection
  - Aperture
- Recycler Lattice
- Beam Lifetime
- Antiproton transfer to the Recycler and stacking
- Commissioning of the cooling system
- Rf manipulation of beam
- Studies related with planed upgrades

Recycler efficiency



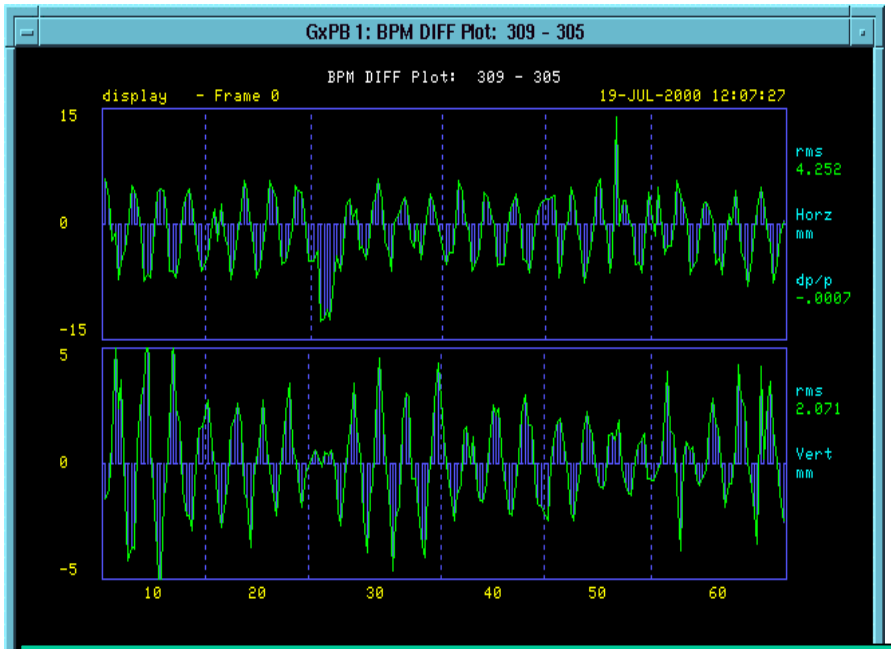
Loss at extraction is due to injection point loss and injection error.

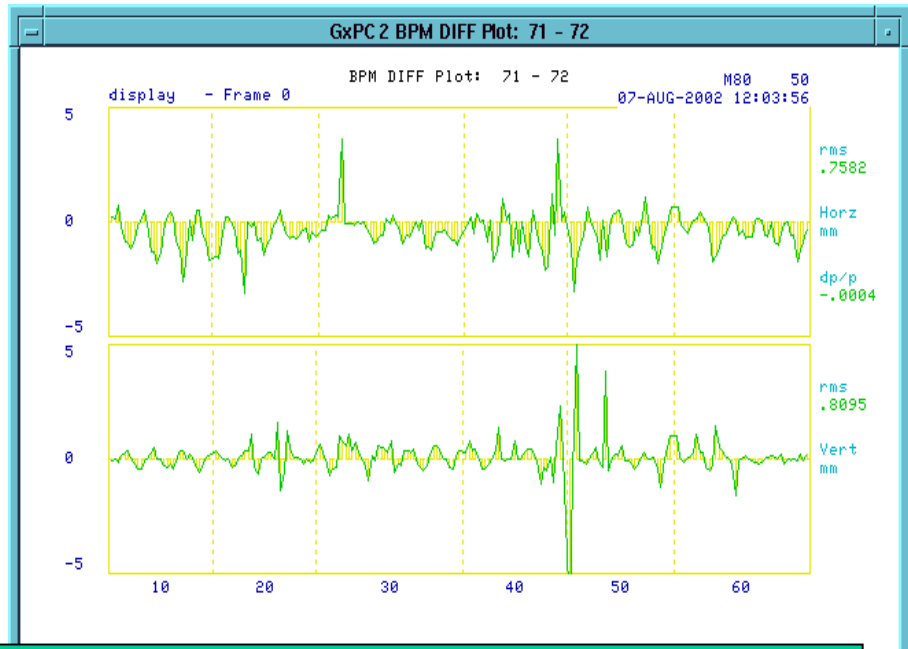
Horizontal Aperture



- After powering all the dipole corrector power supplies a new aperture scan was done.
- Installation of feed down sextupoles was done.
- We measured the horizontal aperture to be about 50 pi mm-mr.
- Vertical aperture is about 40 pi mm-mr.

MI Magnetic Field effect on RR orbit

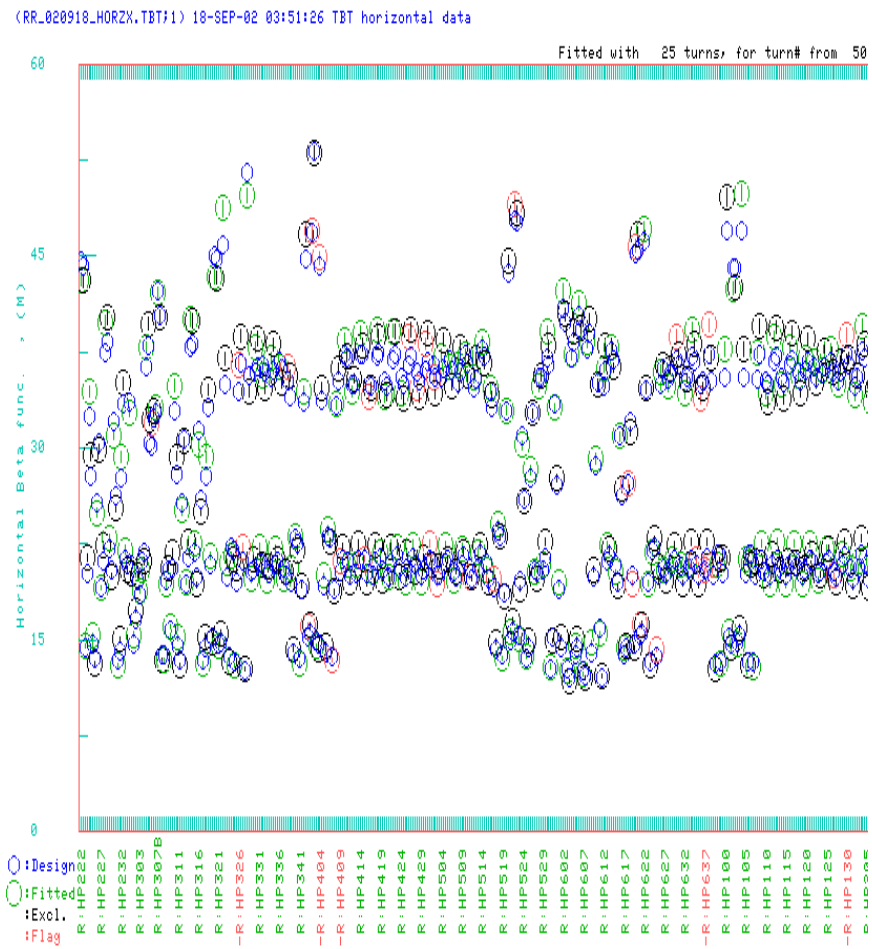




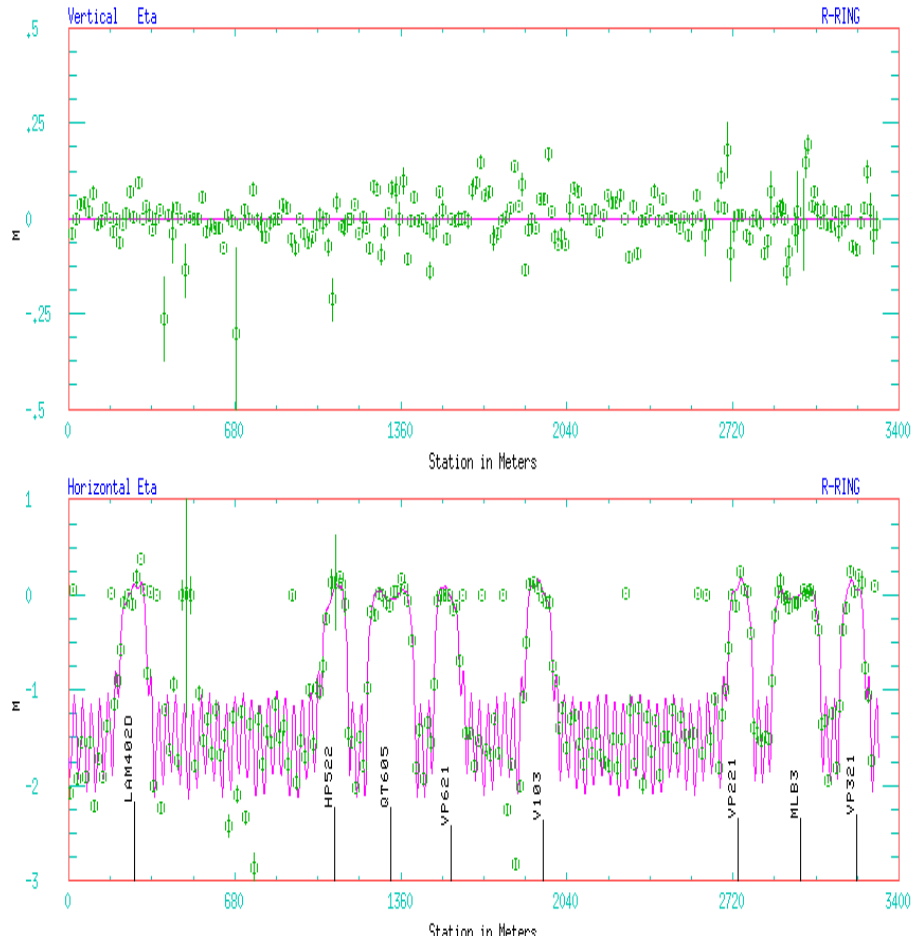
A R&D on shielding revealed that we needed new mu-metal and rapping technique. Old shielding was not very effective.

But the motion in dp/p and tune is causing longitudinal and small transverse emittance growth.This may require an active correction. We plan to add more shielding during next shutdown. We are also looking at feed-forward and feedback techniques.

RR Lattice functions

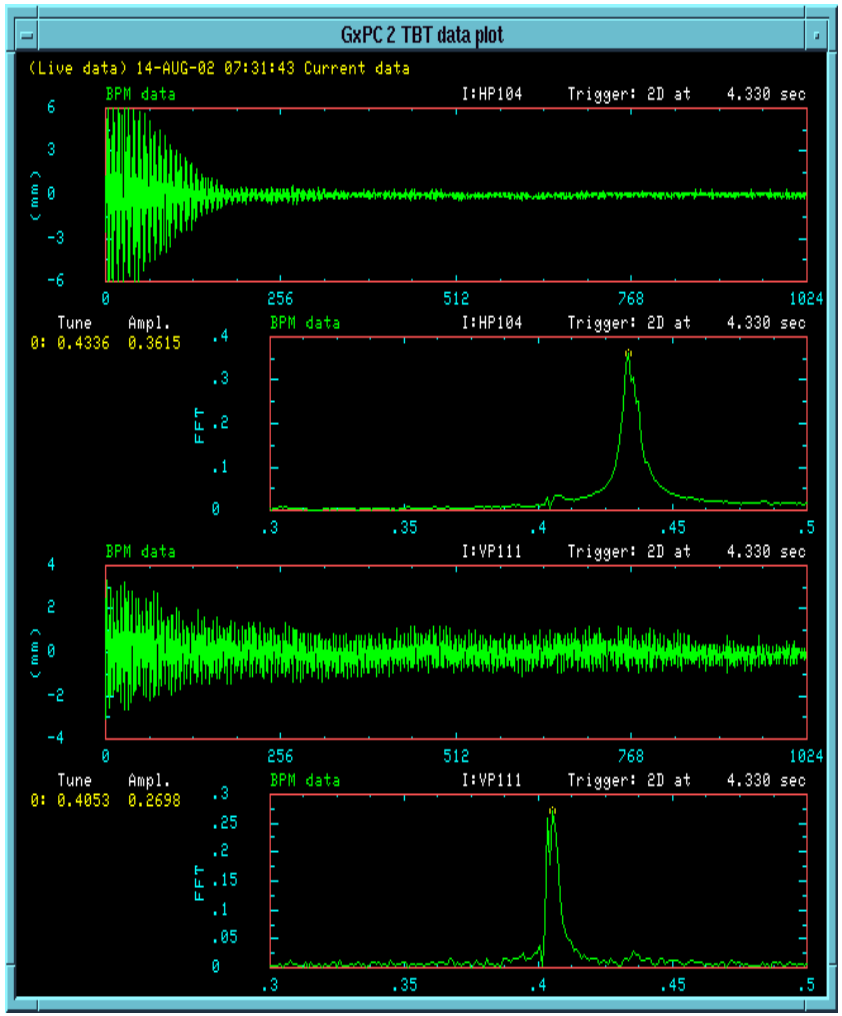


Horizontal Beta

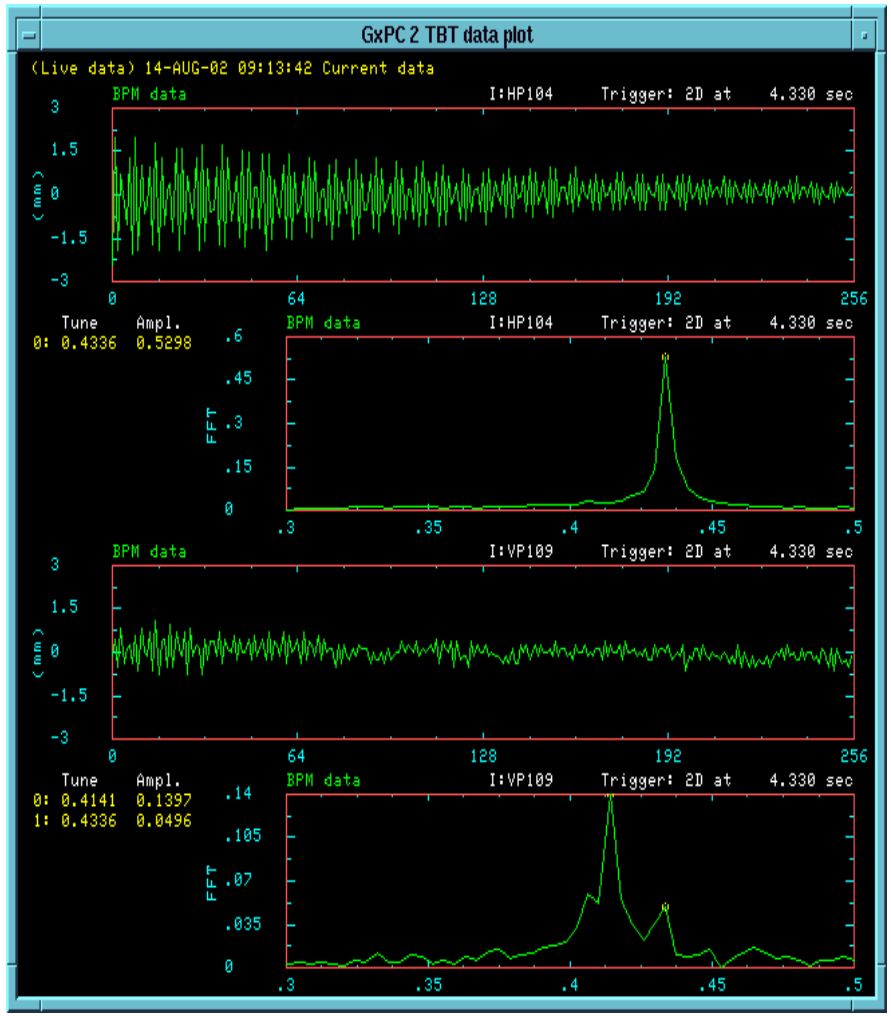


Recycler Dispersion

MI Reverse Tune-up using 53 MHz

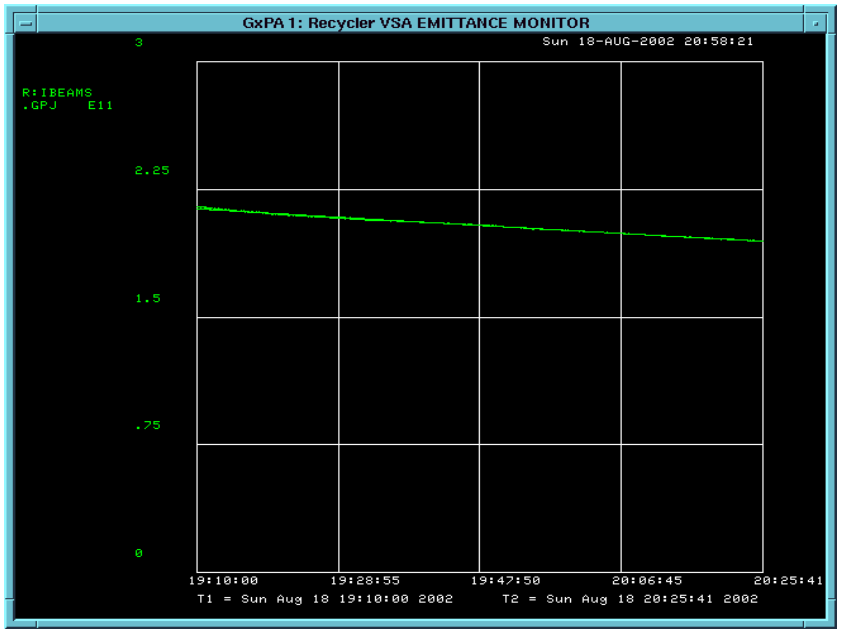


Before tuning.



After tuning.

Recycler Proton Lifetime



•Unscraped proton beam lifetime 13 hours with Main Injector ramping.

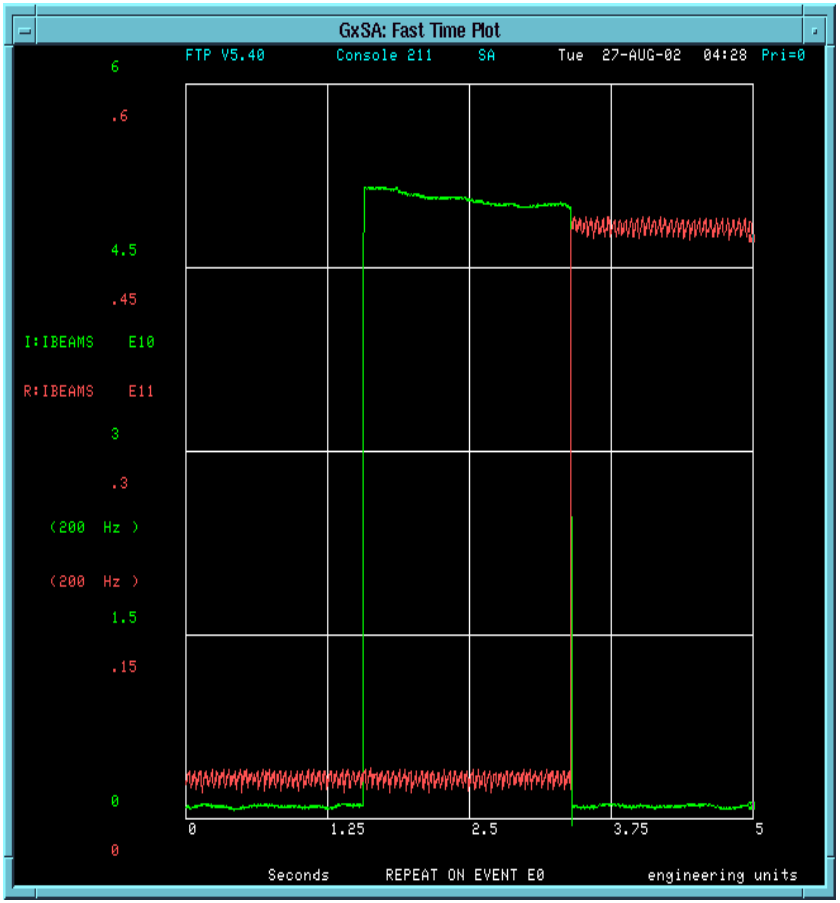
• The aperture does not fill for 2 to 3 hours with Main Injector ramp.

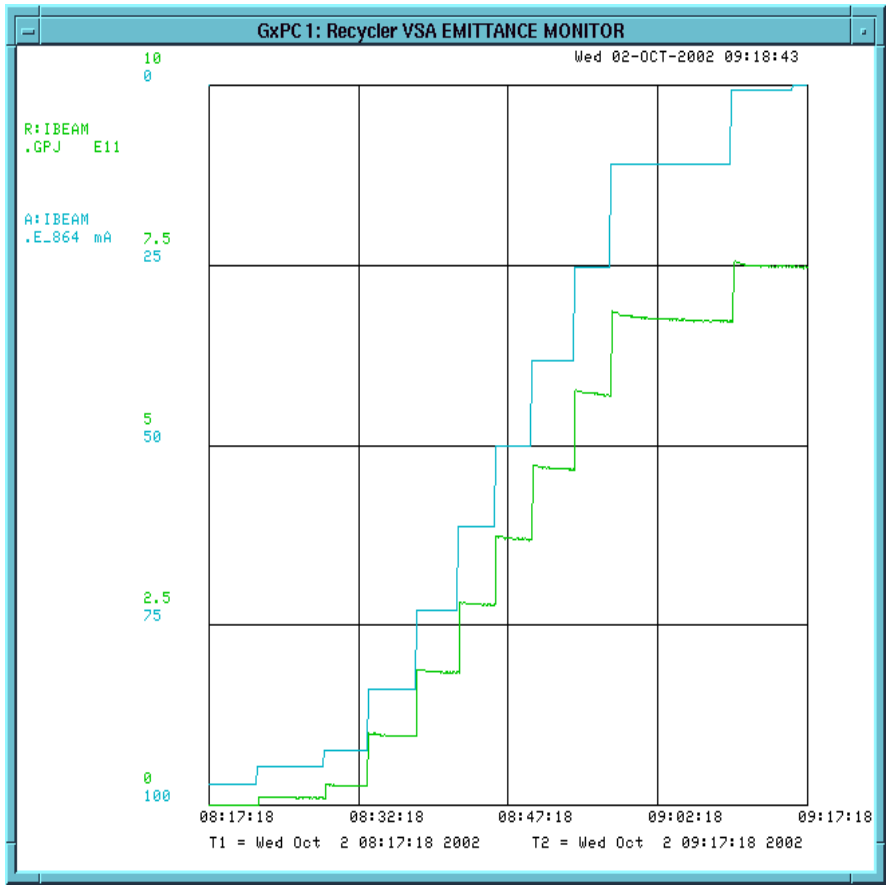
• This is considerable improvement as compared to less than a minute aperture filling after

• We installed all the sextupole feed down correction (Aug 02)

• Complete scan in both H and V planes and centering the beam in aperture.

Antiproton transfer to Recycler

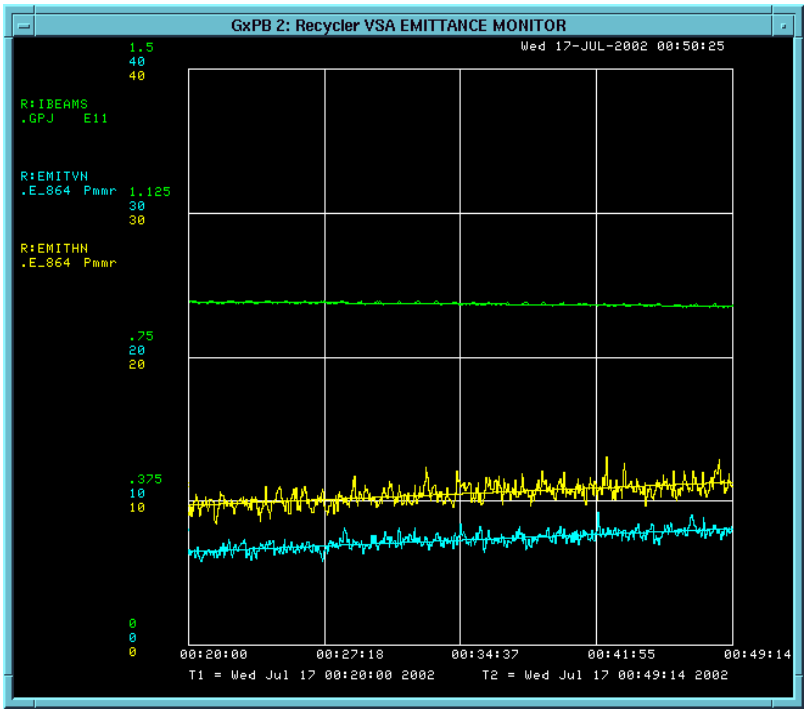


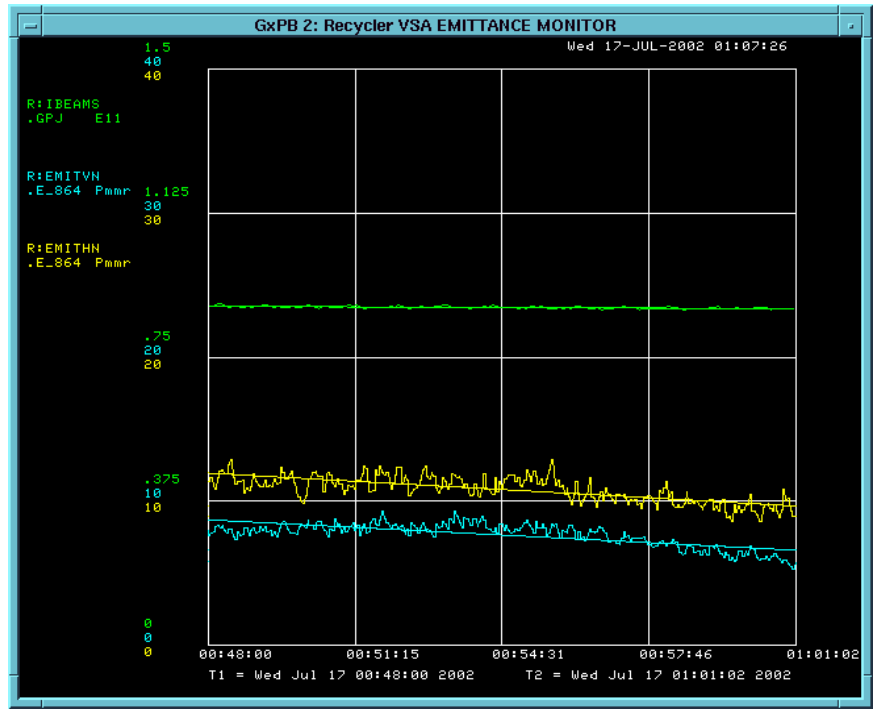


>95% circulating efficiency for 1st injection.

>75% stacking efficiency.

Pbar Heating and Cooling Rate





•pbar heating rate measured at this intensity is about 3-4 pi mm-mr/hour.

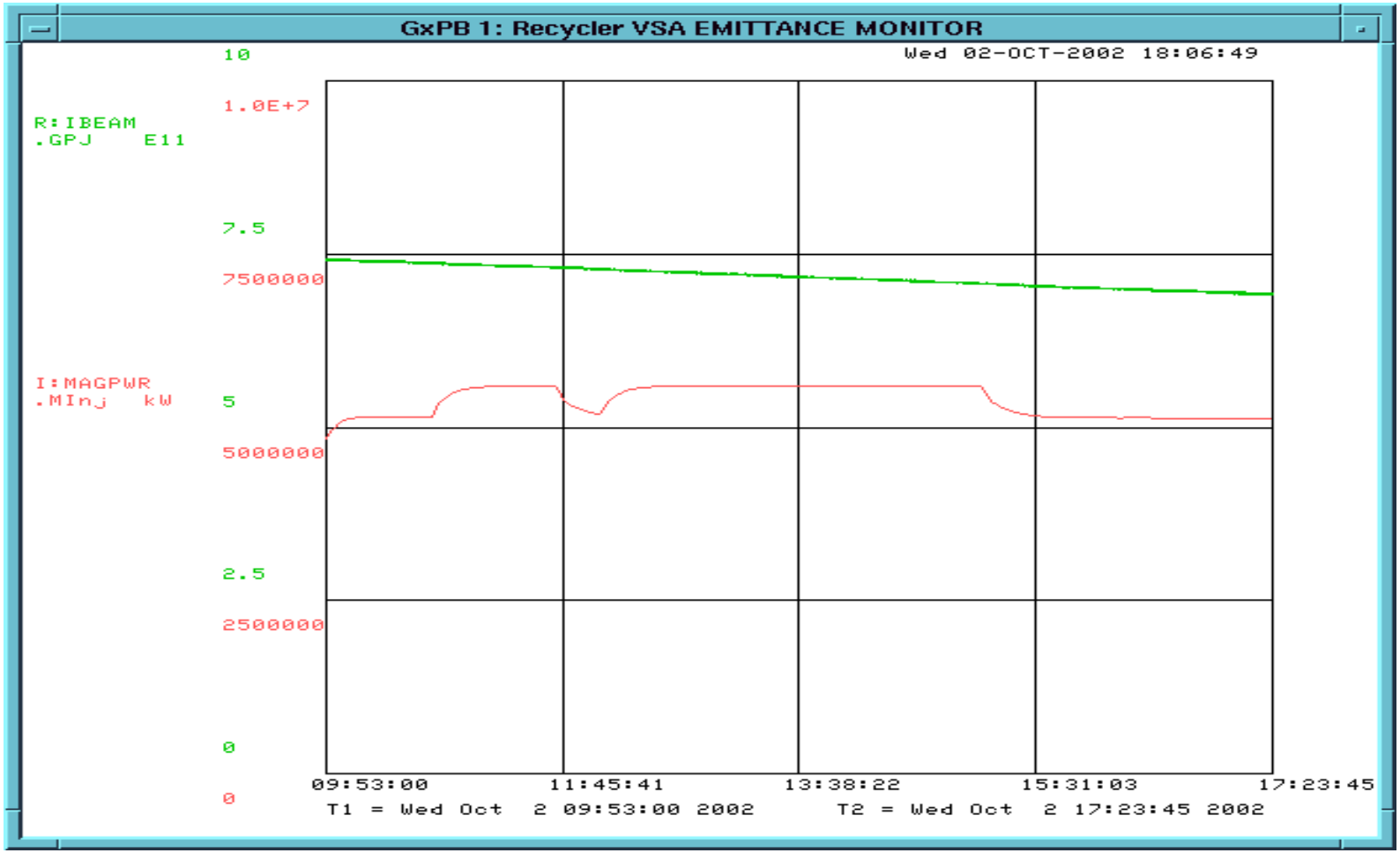
• This growth rate is similar to proton heating rate and is consistent with vacuum related growth (x2).

• The cooling rate is about 10 pi mm-mr/hour.

• This is not a fully optimized system.

• Only 1e11 pbar in stack.

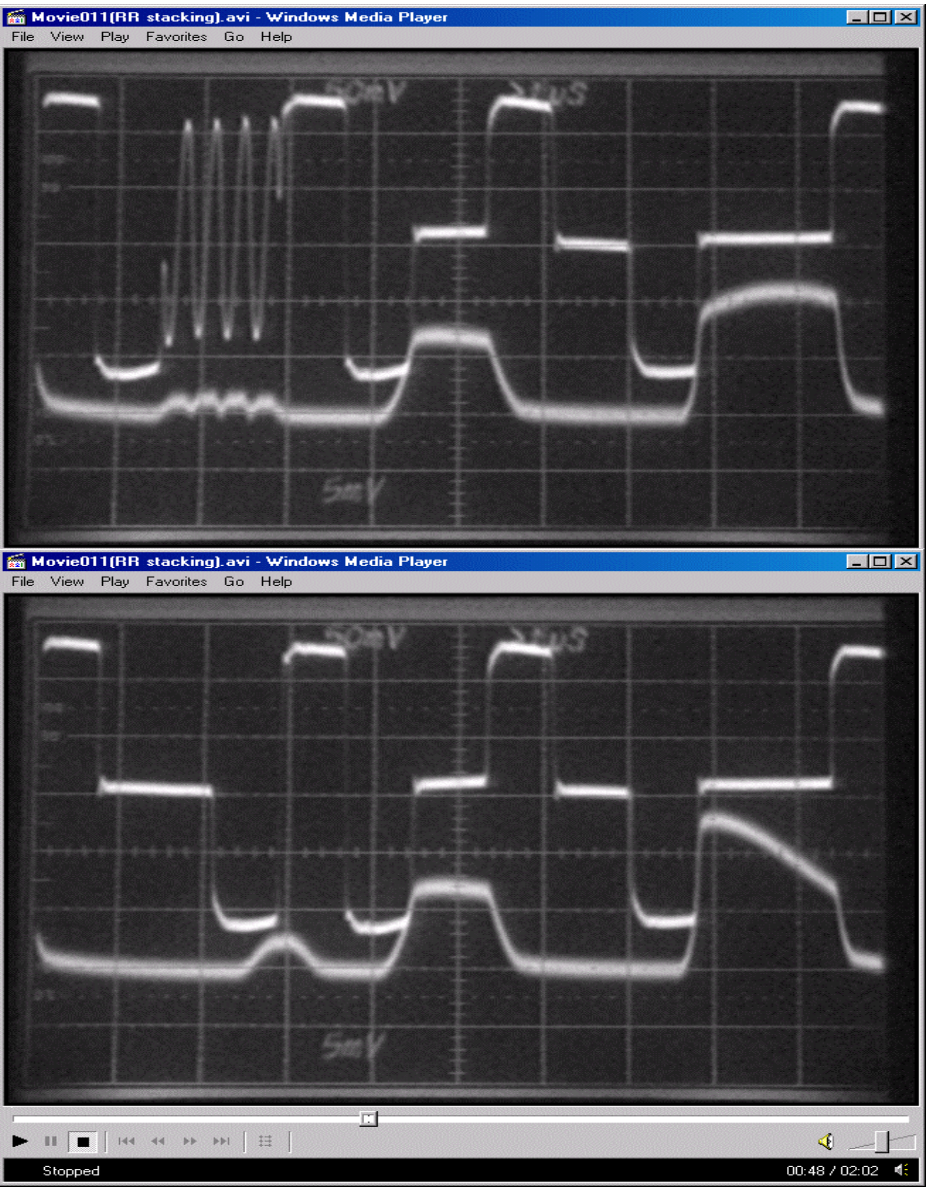
Pbar lifetime

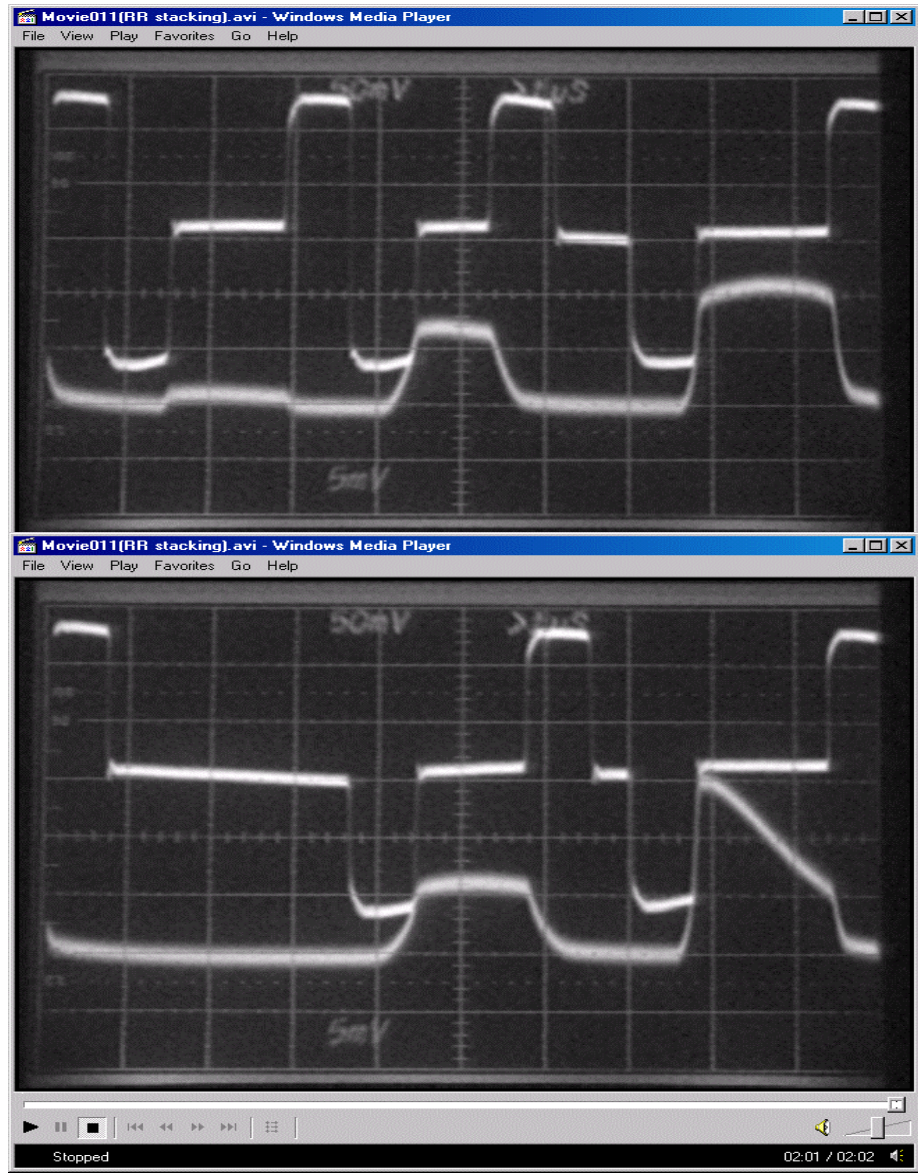


7 hours of store, 105 hours of lifetime for 0.75e12 antiproton.

(Cooling system was partially operational and tuning continues)

Antiproton Stacking RF manipulations

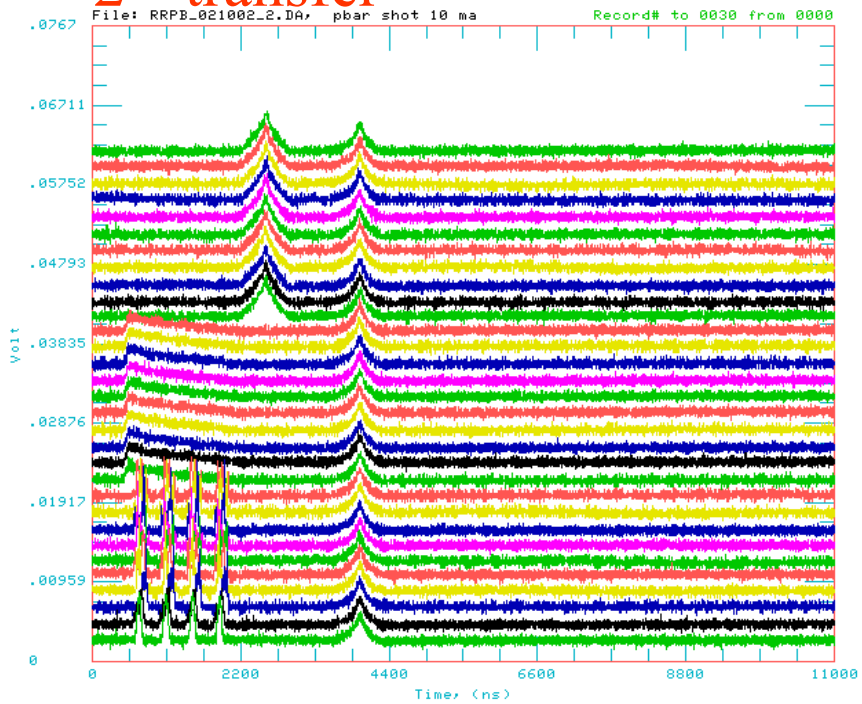




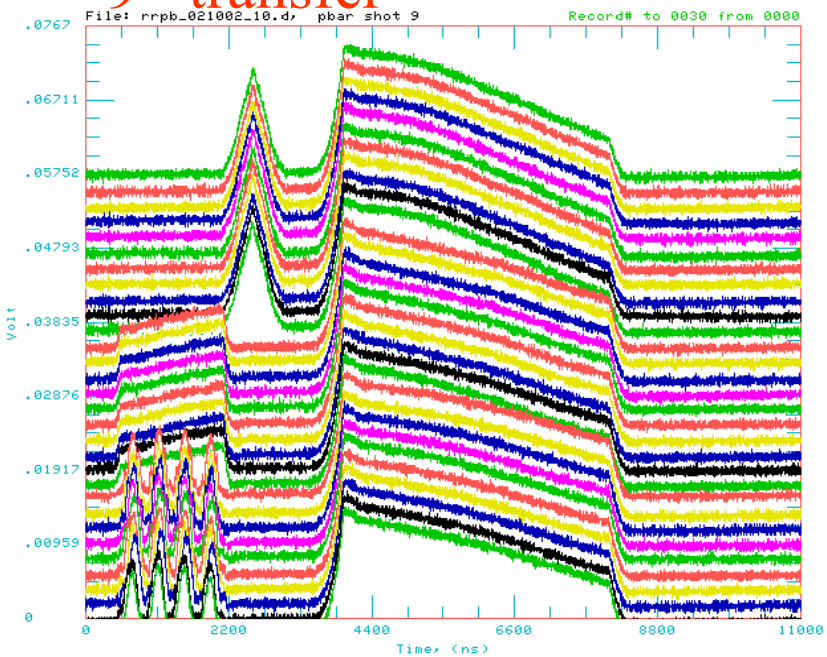
Insignificant amount of beam is leaking from the barrier buckets.

Antiproton longitudinal profile

2nd transfer



9th transfer

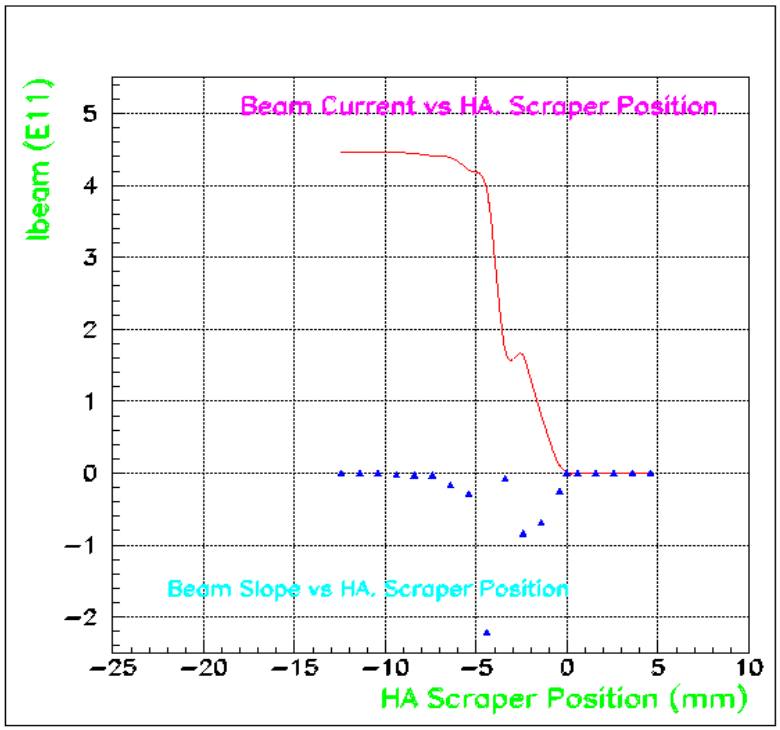


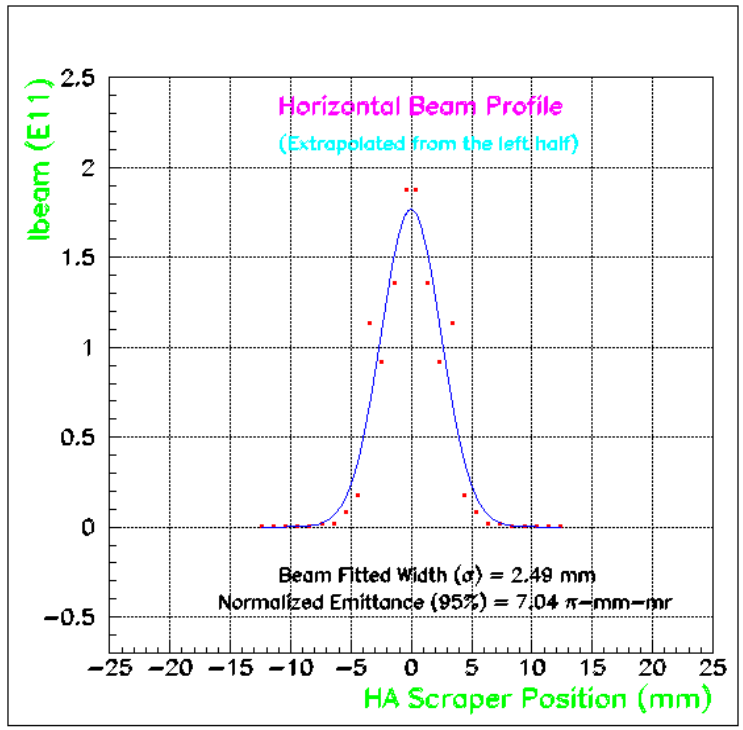
1. Bunches at injection in 2.5 MHz buckets had about 2eVs/bunch(20%)

2. Bunch after squeeze before adding it to main stack is ~9.5 eVs (20%)

3. The beam in stack is ~ 65 eV-sec (large error). There is a slope in the base which was not taken into account in this calculation.

Emittance of the Cooled antiprotons



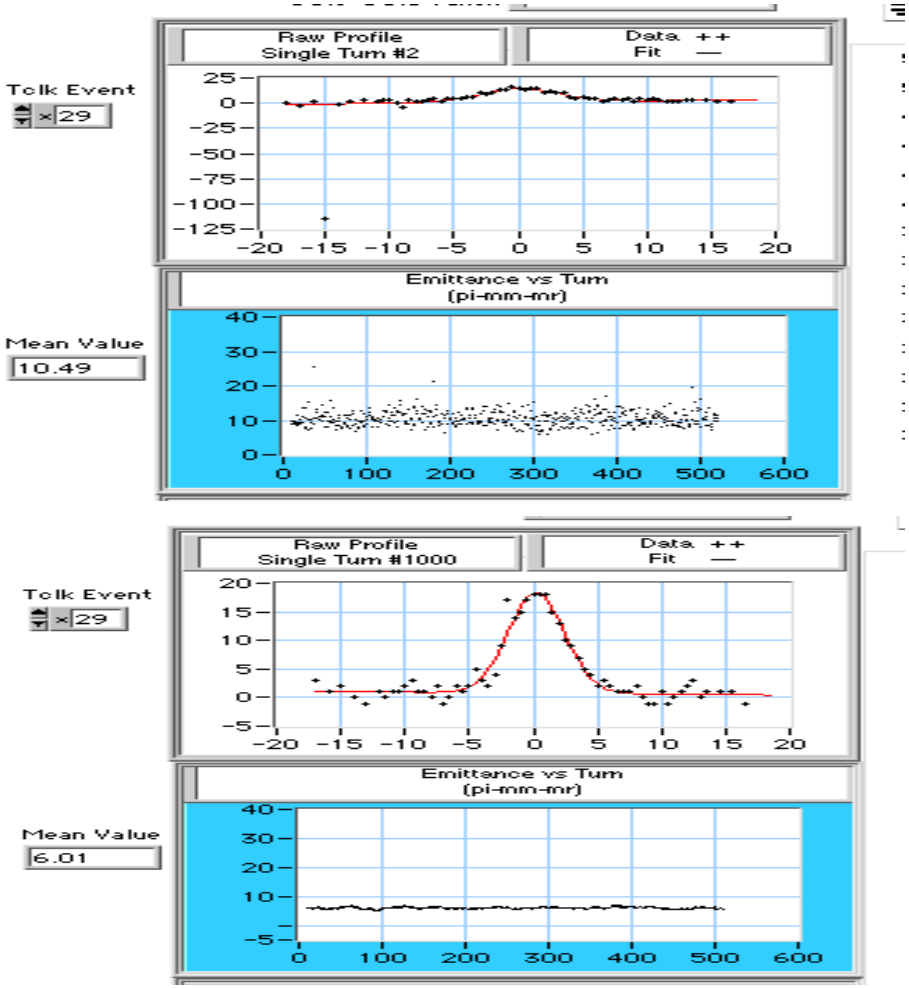


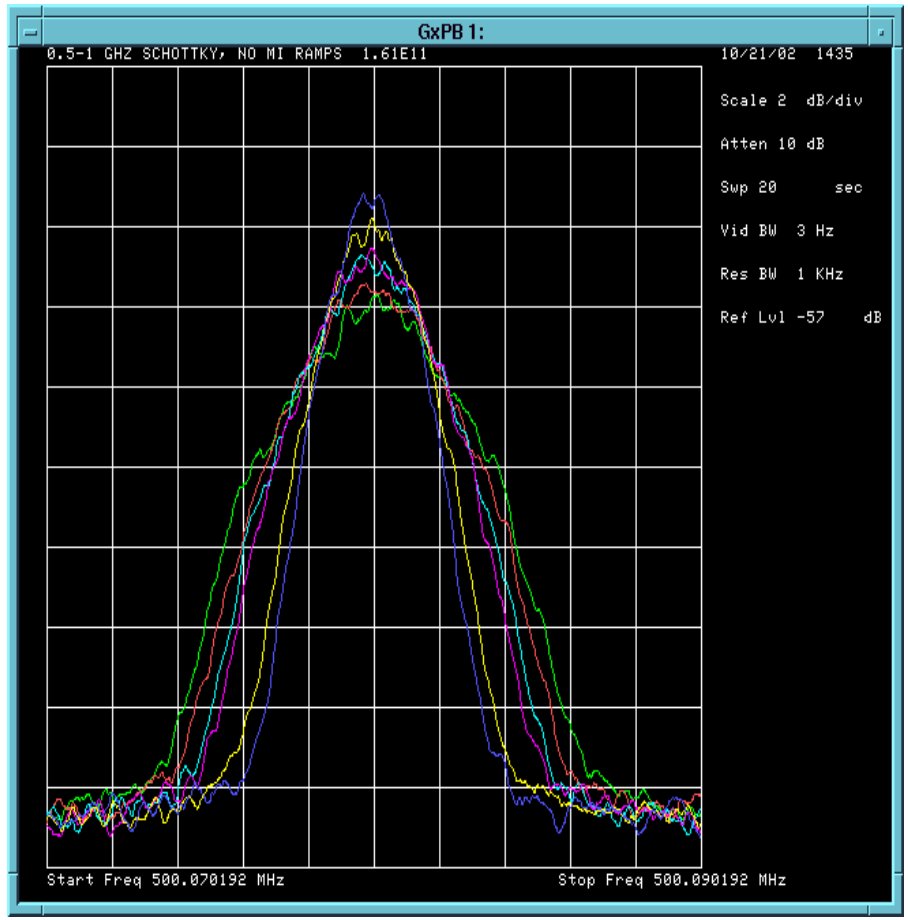
Measured emittance is about 7 pi mm-mr.

We have measured emittance of about 6.5 pi mm-mr in both planes for about 6e11 pbar in the stack.

This measurement will be repeated with more calibrated instrumentation and higher stack size.

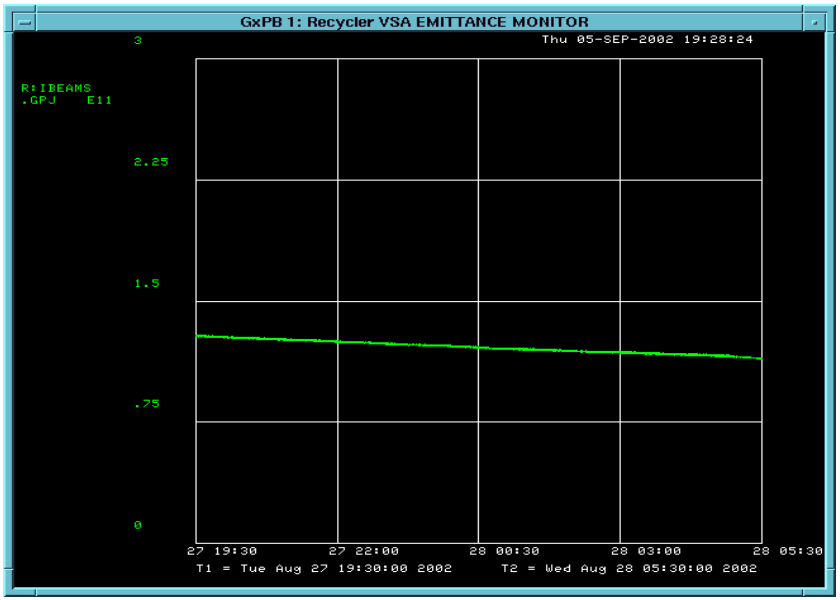
Emittance of the Cooled antiprotons

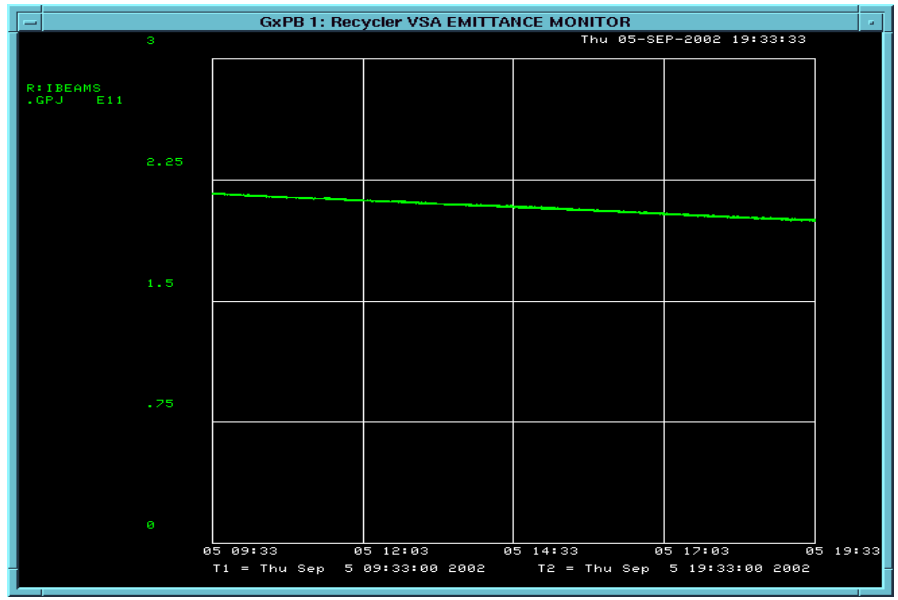


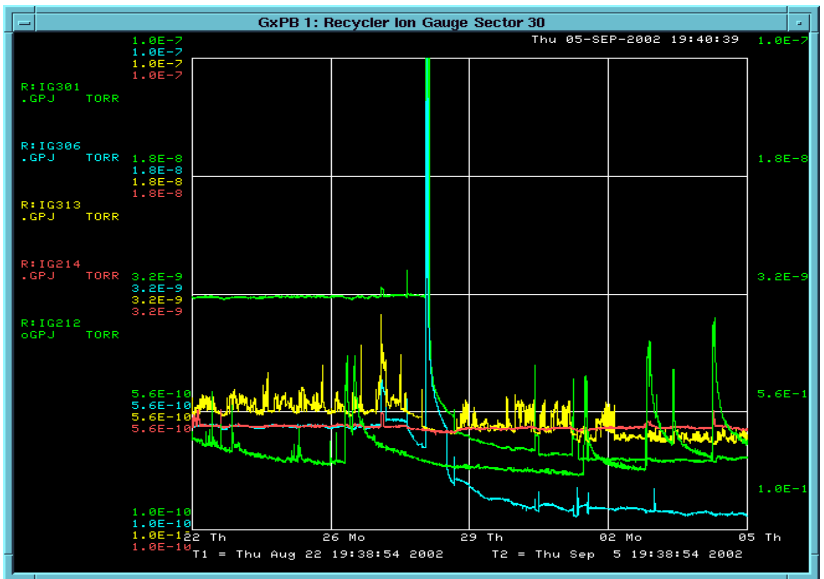


- Transverse Emittance is about 7 pi mm-mr at a stack of 75e10 pbar. IPM needs calibration. It measurement is larger by x2 in H plane than size measured by scraping the beam.

Effect of vacuum on pbar lifetime



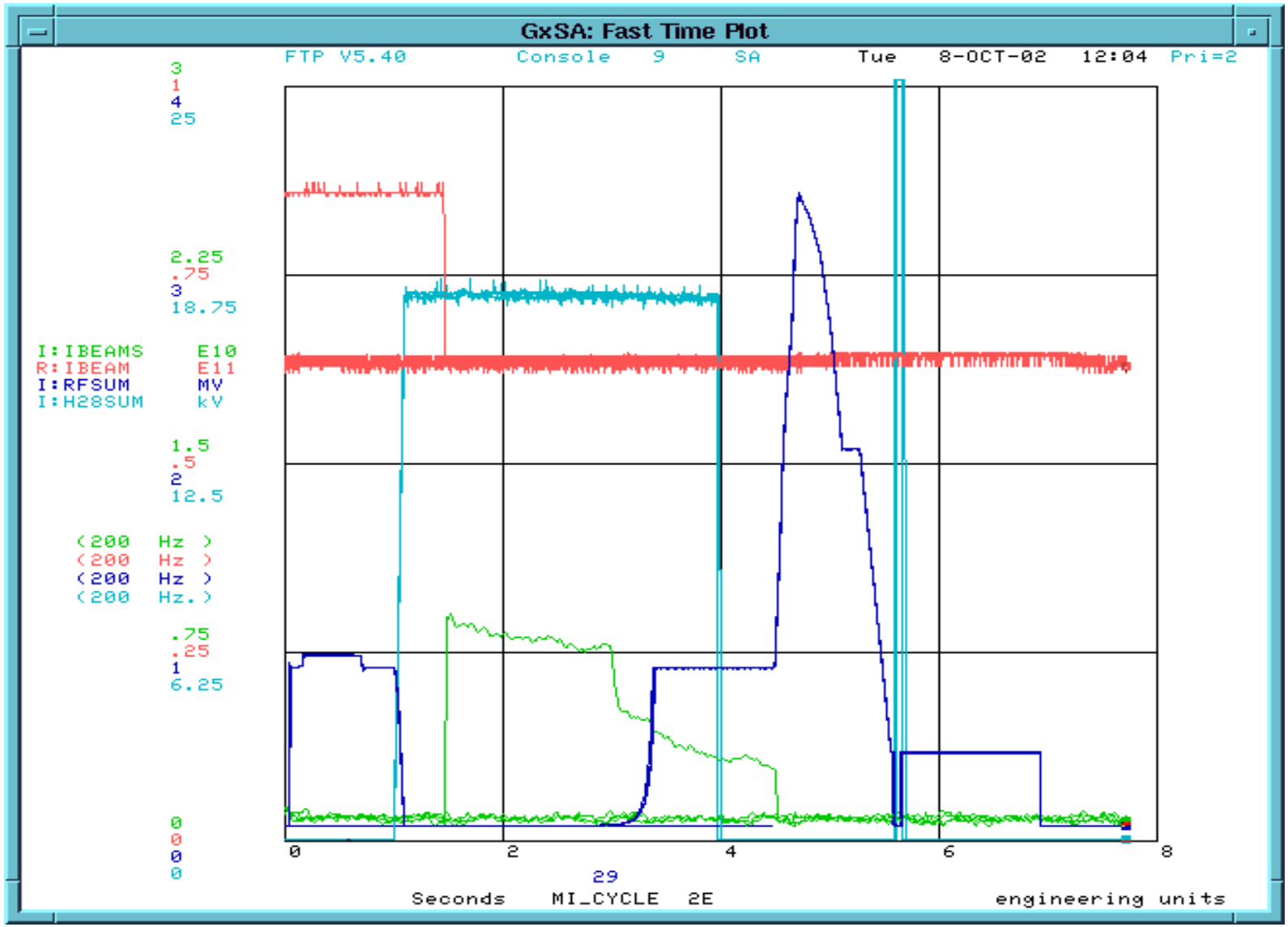




Lifetime improved from 90 hours to 125 hours after improving the MI30 sector vacuum by firing TSP.

Proposed vacuum upgrade will improve this considerably.

Extraction of pbar from Recycler



Physics Issue

- Injection and circulating Efficiency for proton and pbar is about 90%
- Emittance growth is about a factor of 2-4 larger than the design. Significant fraction of this appears to be vacuum related.
- Recycler performance is adversely affected by the Main Injector ramp.
- Circulating and injection lattice and aperture
- Operating point of the Recycler is sensitive to the Recycler orbit.
- Cooling needs further study and optimization.
- RF manipulations need further study and optimization.

Recycler Status

	Integration Goal	Achieved
Number of stored antiprotons	*2e12*	*0.9e12*
Transfer efficiency(Acc→RR)	*>90%*	*83%*
Stacking efficiency	*>85%*	*75%*
Lifetime (2e12) (hrs)	*100*	*105* (0.7e12)*
Equilibrium Normalized Emittance *pi mm-mr*	*<10*	*~7* (0.5e12)*
Emittance Growth pi mm-mr/hr	<2	~ 5
Longitudinal Emittance (eV-Sec)	<54	75

* The Stochastic cooling system is being tuned and new hardware are being installed. This performance is expected to improve.

Technical Issues

- Instrumentation Upgrades
  - Beam Position Monitor
  - Beam Line Tuner
  - Flying Wire
  - Ion Profile Monitor (Physics Understanding)
  - Schottky Detectors
  - Injection Damper
  - Reliable, calibrated and operational Instrumentation
  - RF power and manipulations for injection, stacking and extraction

Technical Issues…

- We need to develop several software to support new hardware being placed in the Ring.
- We also need to develop several software for operation and physics analysis.
- Accumulator to Recycler transfer
  - At present there is a momentum and frequency difference between the Accumulator and Recycler.
  - We need to measure the central momentum for the Recycler. We need to redefine the 8.9 GeV/c for the complex.
  - We are proposing that all transfer takes place in 2.5 MHz.
  - We need a procedure which uses MI as a transfer line.

Mechanical Upgrades of the Recycler

- Vacuum upgrades
  - Double ion pump in the Recycler
  - Install insulator inside the CFM for higher temperature bake.
  - Bake at a higher (>110 deg C) temperature for 4 days.
  - Install more gauges and RGA
  - Find and eliminate small leaks
- Lattice Upgrade of the Recycler
  - Remove stuck old magnetic heater tapes from 24 magnets
  - Remove windows and use differential pumping
  - Additional correctors
  - Additional Magnetic shielding at select locations

Recycler Integration

We have started working on the integration of the Recycler into the Accelerator complex.

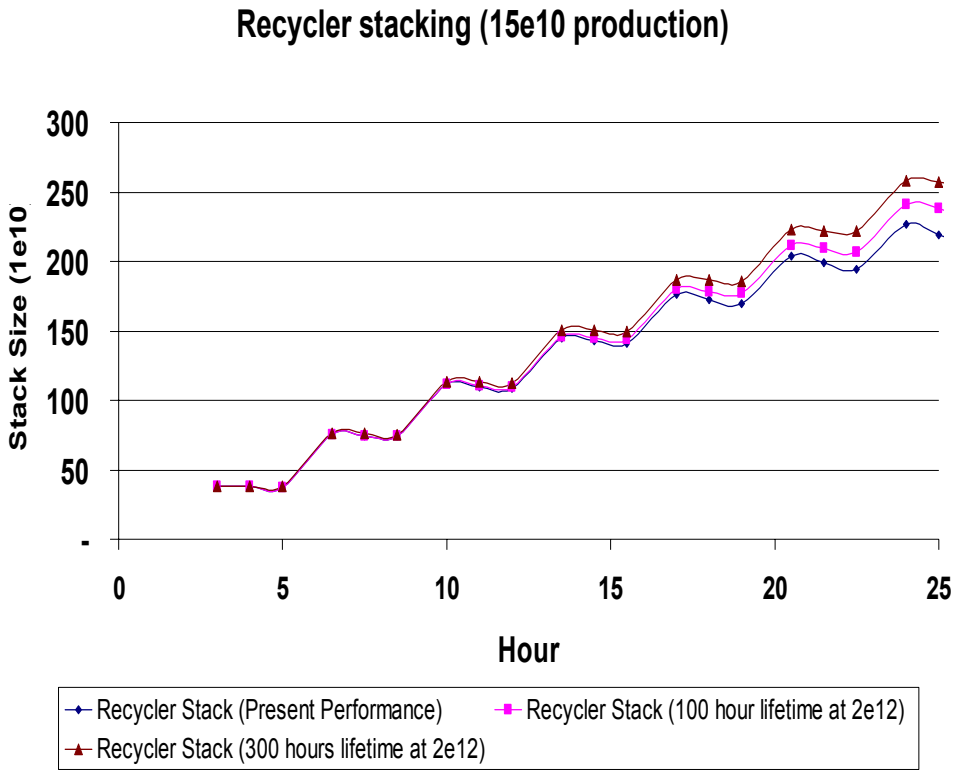
- Stack efficiently, reasonable lifetime and emittances.
- Re-bunch cooled beam in 2.5 MHz, transfer to MI and accelerate in MI to 150 GeV with >90% efficiency, using 53 Mhz.
- Develop 2.5 MHz acceleration in MI through transition to eliminate coalescing of beam at 150 GeV.

At start this has to break even with Accumulator stacking and show potential of improvement

- If the stacking rate in the Accumulator improves to 15e10 pbar/hour.
- Similar or better emittance of the beam to Tevatron.

Simulated Recycler Stacking

- This calculation assumes slightly improved Recycler performance in stacking efficiency of 85% and present intensity dependent lifetime.
- It is compared with a calculation where lifetime of 100 hours and 300 hours at 2e12 with small intensity dependence.



- 1.5e11 pbar/hour
- Transfer every 3 hours
- Recycler shot setup 30 mins.
- 2e12 in 20-24 hours, depending on stacking efficiency at large stack size.

Summary

- Over the last year we have made significant progress in the Recycler performance.
  - Recycler circulating antiproton beam efficiency >95% and stacking efficiency of about 75% has been achieved.
  - Antiproton lifetime >100 hours for >75e10 pbar.
- We still have several issues related to RF manipulations at stacking and extraction.
- We have proposed several upgrade to improve the performance of the Recycler.
- Recycler is close to being a machine which can be integrated into the complex.
- The proposed Recycler upgrade will make the Recycler fully operational.